

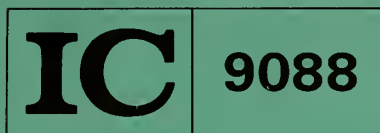
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Reliability Prediction for Computerized Mine-Monitoring Systems

By Raymond M. Kacmar and Edward F. Fries



UNITED STATES DEPARTMENT OF THE INTERIOR

(United States, Bureau of Mines)

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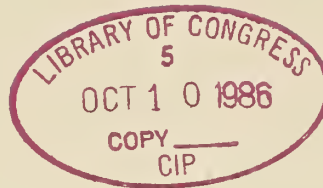


UNITED STATES DEPARTMENT OF THE INTERIOR

Donald Paul Hodel, Secretary

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CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	2
System descriptions.....	2
Reliability predictions.....	2
Methodology.....	2
Parts-count reliability.....	4
Prior reliability data.....	4
Reliability prediction assumptions.....	4
Reliability models.....	5
Prediction data and analysis.....	7
Environmental impact on equipment.....	8
Conclusion.....	8
Bibliography.....	13

ILLUSTRATIONS

1. Block diagram of system A.....	3
2. Block diagram of system B.....	3
3. System A reliability configuration.....	5
4. System B reliability configuration.....	6
5. Sample form for assembly-rate summary.....	7
6. Sample form for microcircuit failure-rate summary.....	8
7. G_F environment for system A.....	9
8. G_F environment for system B.....	9
9. Data processing subsystem for systems A and B.....	10
10. Communications subsystem for system A.....	10
11. Power subsystem for system A.....	10
12. Transducer subsystem for system A.....	10
13. Communications subsystem for system B.....	11
14. Power subsystem for system B.....	11
15. Transducer subsystem for system B.....	11
16. System A reliability--adjusted.....	12
17. System B reliability--adjusted.....	12

TABLES

1. Functional subsystems.....	6
2. Environmental impact on equipment.....	11

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C degree Celsius

MM million

h hour

V volt

Hz hertz

RELIABILITY PREDICTION FOR COMPUTERIZED MINE-MONITORING SYSTEMS

By Raymond M. Kacmar¹ and Edward F. Fries²

ABSTRACT

This report presents the Bureau of Mines research on the hardware reliability prediction for two Bureau monitoring projects. The basic concepts of reliability predictions are introduced along with the reliability models and assumptions used for this particular evaluation. The results of the reliability predictions are for ground-fixed and naval-sheltered environments.

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INTRODUCTION

By using computerized systems that are appearing in the marketplace, mine operators now can monitor and display the status of underground conditions. However, before they buy, install, and depend on these systems they need to know how reliable the data from the system will be; also, they need to predict how future expansions will affect system reliability. The Bureau of Mines is conducting research to determine the reliability of current monitoring systems and also to demonstrate that standard reliability prediction techniques can be modified to predict the reliability of equipment operating in a mine environment.

The mine monitoring systems researched for this report are electromechanical

systems that remotely sense various environmental and operational parameters and transmit the data to a central location where the data are analyzed and/or displayed. The equipment normally required to perform these functions consists of transducers, telemetry, one or more computers, and the associated peripherals and input-output interfaces. In the basic system, the output from a transducer is converted to a format that enables a signal to be transmitted to a central computer station. There, a processor (or system of processors) tabulates the data, compares it with present alarm conditions, displays results, logs the data for future reference, and performs other calculations and data management.

SYSTEM DESCRIPTIONS

Both systems selected for these reliability predictions (to be referred to as system A and system B) have been installed as research projects in conjunction with the Bureau. System A is located in a research mine, owned by the Bureau, in Allegheny County, PA. System B is located in a commercial mine in Indiana County, PA. Although the system configurations are different, they are both representative of current technology. The computer stations used for these systems were selected by the Bureau under competitive bid. They consist of a microprocessor-based controller with a cathode ray tube (CRT) and floppy disk drive and two printers.

It should be noted that both systems are currently being modified to upgrade system capabilities. Therefore, the reliability predictions in this report will only apply to the original system configurations. However, these predictions can be easily adjusted once the hardware modifications have been completed.

The telemetry system used for system A employed a four-wire frequency

shift-keyed communications link. Two of the wires were used to transmit data and two were used to receive data. On the surface, a telemetry card and local modem connected the computer to the telemetry line. At the sensing locations, an analog-to-digital (A/D) converter and a remote modem connected the transducers. Previously, there were five communication "outstations" being used. One station was located on the surface and four stations were located underground. A block diagram of this system is shown in figure 1.

For system B, two "trunk lines" (four-wire telemetry cables, each consisting of two power lines and two data lines) were used to monitor methane, carbon monoxide, and airflow. A block diagram of this system is shown in figure 2.

The transducers sent measurements to the central station through an A/D telemetry card. The analog voltage from the transducer is converted to an 8-bit digital message and is then telemetered to the computer.

RELIABILITY PREDICTIONS

METHODOLOGY

The standard procedures for performing reliability predictions are described in

the military handbook (MIL-HDBK) 217D, "Reliability Prediction of Electronic Equipment." When possible, the methods in 217D, paragraph 5.1, are to be used.

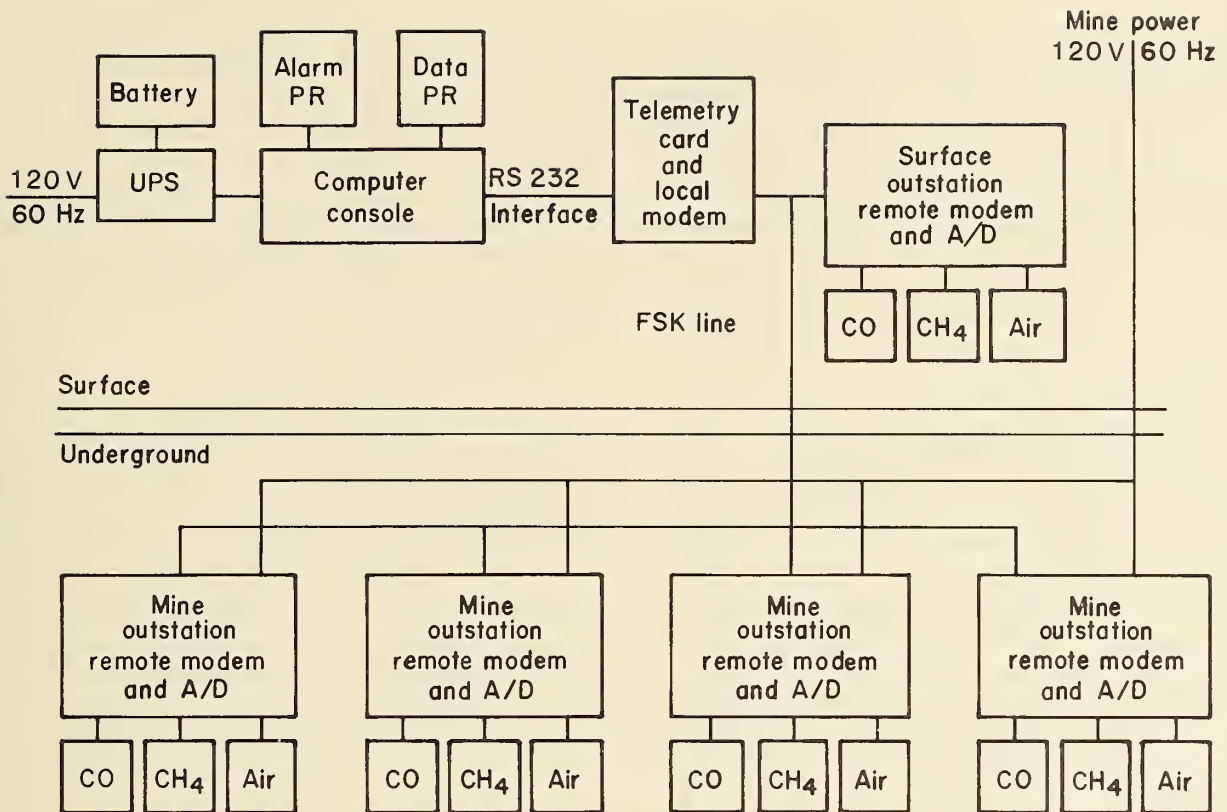


FIGURE 1.—Block diagram of system A.

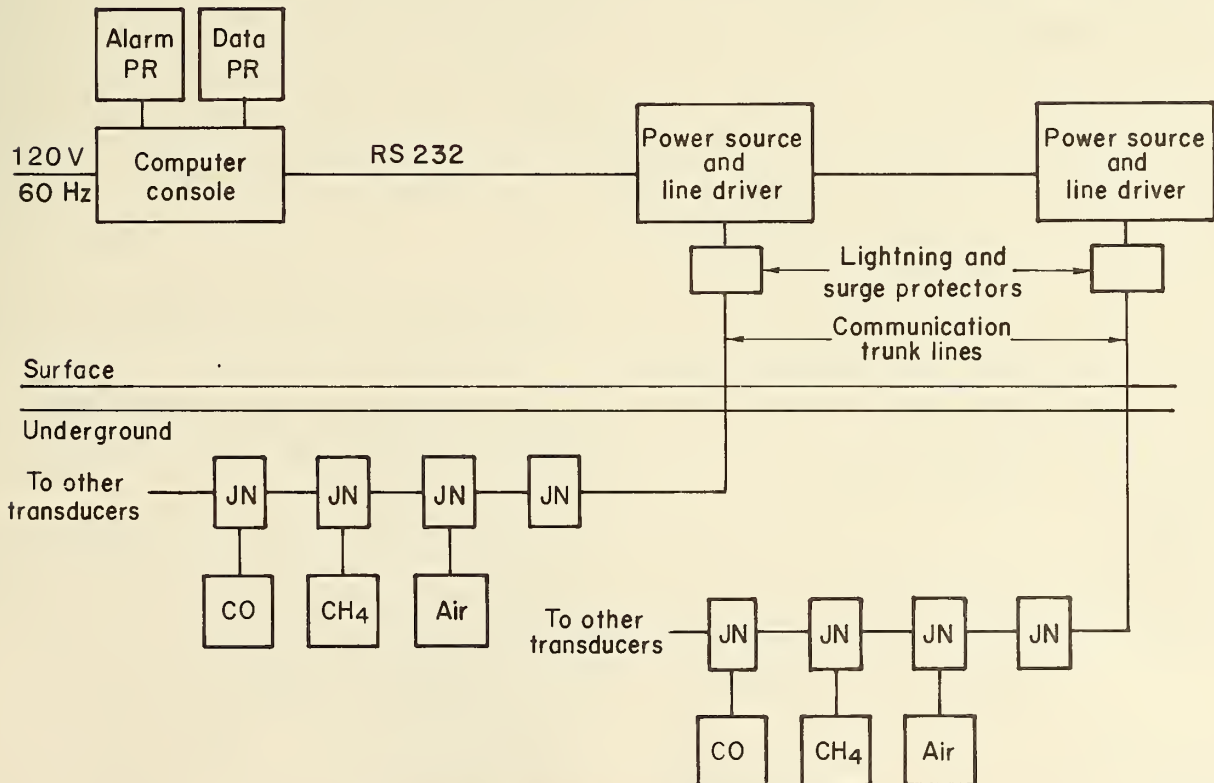


FIGURE 2.—Block diagram of system B.

The equations contained in this section of the handbook require the detailed knowledge of the stress and quality levels of the components in the equipment under study. However, this detailed information on the parts used for the monitoring systems was not available for this analysis. Therefore, a combination of the following two methods was used to arrive at the predicted system reliability for the two configurations: parts-count and prior experience.

Parts-Count Reliability

When the methods of paragraph 5.1 cannot be used, MIL-HDBK 217D recommends the use of paragraph 5.2, "Parts-Count Reliability Prediction." This method is based on the type and quantity of the parts used. For this evaluation, it was used for equipment and assemblies whose parts lists were available or could be derived. This prediction procedure has limitations, and past experience has shown it to be conservative. Average stress levels are assumed for parts such that the system reliability can be expressed as

$$MTBF (SYSTEM) = \frac{1}{\sum_{i=1}^n N_i (\lambda_{G_i} \pi_{Q_i})} \quad (1)$$

Where for a given environment

MTBF (SYSTEM) = the system average time between failure, h,

λ_G = generic failure rate for the i^{th} generic part, failures/MM h,

π_Q = quality factor for the i^{th} generic part,

N_i = quantity of the i^{th} generic part,

and n = number of different generic part categories.

The following gives a sampling of the assumptions used for the parts-count prediction:

1. Ambient temperature (T_A) = 40° C for ground-fixed environment (G_F).

2. Applied stress ratio = 0.5 = actual power dissipated per maximum rated power.

3. Uses average complexities; e.g., any integrated circuit in 501-1,000 gate range uses 875 gates for calculation.

4. A limited number of quality factors.

Prior Reliability Data

For this method, reliability data for similar parts used in other applications were used. This information was obtained from conversations with reliability experts at the Department of Air Force, Rome Air Development Center (RADC), Reliability and Maintainability Engineering Section (RBER), Griffiss Air Force Base, New York. This method was used since several components and assemblies were not of the type that lend themselves to parts-count prediction techniques or could not be broken down into their constituent parts. As a result, the reliability of these assemblies were based on information obtained from RADC personnel who have had experience with similar equipment in the past on Air Force systems. Where complexities, environment, and/or duty cycles differed from that of the equipment under study, adjustments were made by RADC.

RELIABILITY PREDICTION ASSUMPTIONS

As a baseline for the prediction, other assumptions were necessitated as follows:

1. Series model.--A series model was assumed such that a failure of any subsystem or assembly caused a system failure.

2. Duty cycles.--All equipment was assumed to be operated at 100% of the system's operational time with the following exceptions:

a. Alarm printer.--The alarm printer was assumed to operate only 10% of the time where the status printer was assumed to operate 100%. This assumption is based on the fact that the alarm printer only operates to output alarm conditions.

b. Disk drive and controller.--These assemblies were assumed to be required 5% of the time because they are used only to initialize the system.

3. Environmental conditions.--The methodology for the prediction was in accordance with MIL-HDBK 217D, which does not have a mine environment. The Environmental Impact section assesses the system reliability in different environments. For the prediction baseline, a ground-fixed environment was assumed.

4. Parts quality.--As a baseline, commercial plastic devices were assumed for integrated circuits and semiconductors (active devices). Passive devices such as resistors and capacitors were assumed to be of commercial quality.

5. Sensing elements.--The reliability of sensing elements themselves was not considered. It was assumed that preventive maintenance made their failure rate contribution negligible. Electronics

associated with the sensing function are included.

6. Software reliability.--The reliability of the system software was not evaluated for this report. However, similar methods exist to determine software reliability but are beyond the scope of this report.

RELIABILITY MODELS

For this analysis, the two system configurations were separated into four functional subsystems: data processing, communications, power, and transducers. This functional designation was made to simplify future comparison between predicted and actual operation. Table 1 lists the assemblies composing the functional subsystems at each location. Figures 3 and 4 indicate how the systems were configured for the reliability models with each block (or assembly) being

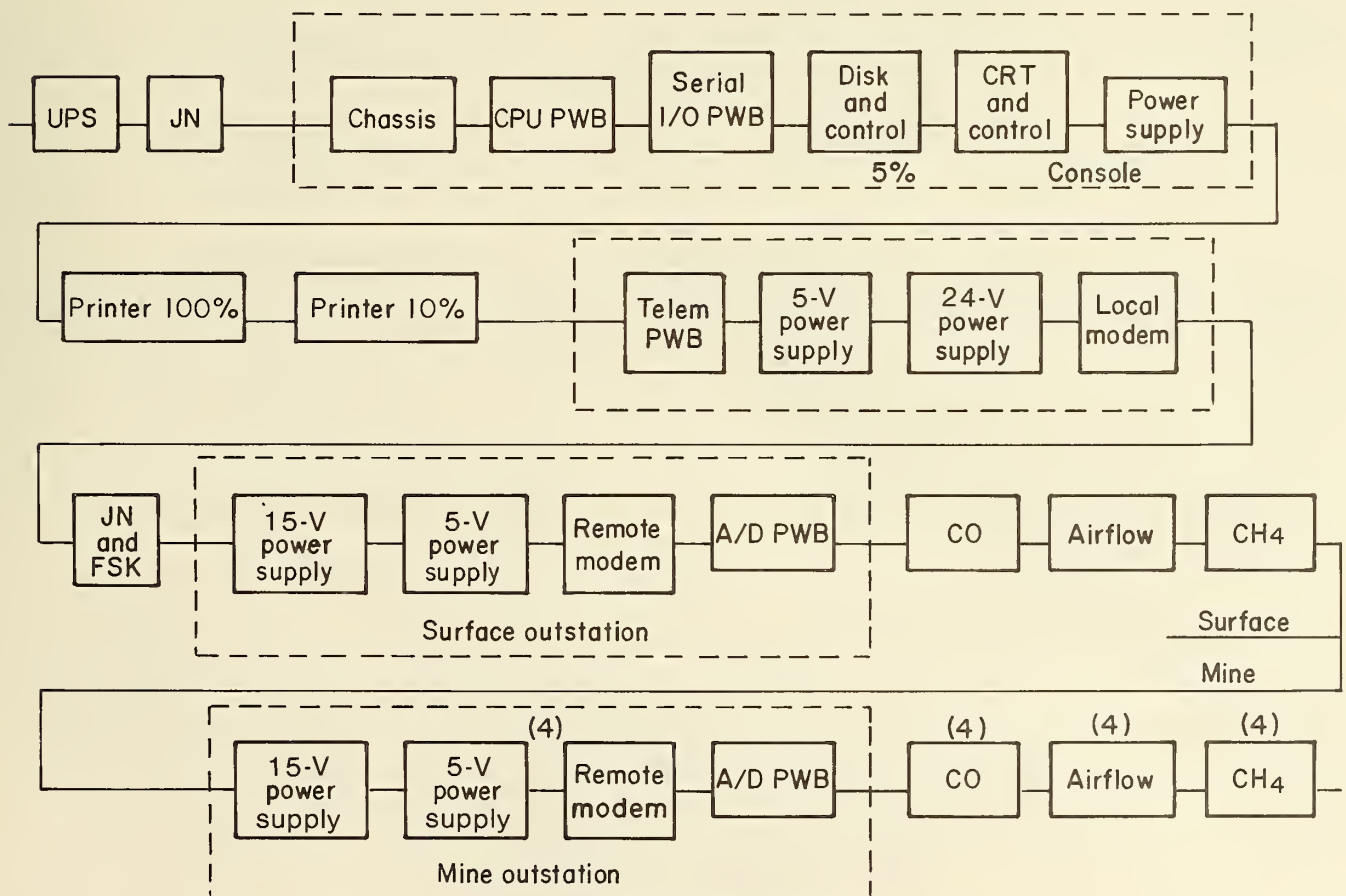


FIGURE 3.—System A reliability configuration.

required for the operational success of the system. Using this reliability model and the four functional subsystems

previously discussed, the MTBF of the system can be expressed as follows:

$$MTBF = \frac{1}{\lambda(DPS) + \lambda(COMM) + \lambda(PS) + \lambda(TRANS)}, \quad (2)$$

where $\lambda(DPS)$ = failure rate for the data processing subsystem failures/MM h,

$\lambda(PS)$ = failure rate for the power subsystem,

$\lambda(COMM)$ = failure rate for the communication subsystem,

and $\lambda(TRANS)$ = failure rate for the transducer subsystem.

TABLE 1. - Functional subsystems

Site subsystem	System A	System B
Data processing.....	1 console and 2 line printers.	1 console and 2 line printers.
Communications.....	Telemetry with local modem: 1 surface outstation, 4 mine outstations, junction boxes, connectors.	1 line driver assembly, 13 A/D boards, 13 junction boxes, connectors.
Power.....	1 uninterruptible power supply, junction boxes, power lines, connectors.	Transient protection, 2 junction boxes, connectors.
Transducers.....	1 surface outstation and 4 mine outstations with 1 each CO, airflow, and CH ₄ transducers.	5 CO, 5 airflow, and 3 CH ₄ transducers.

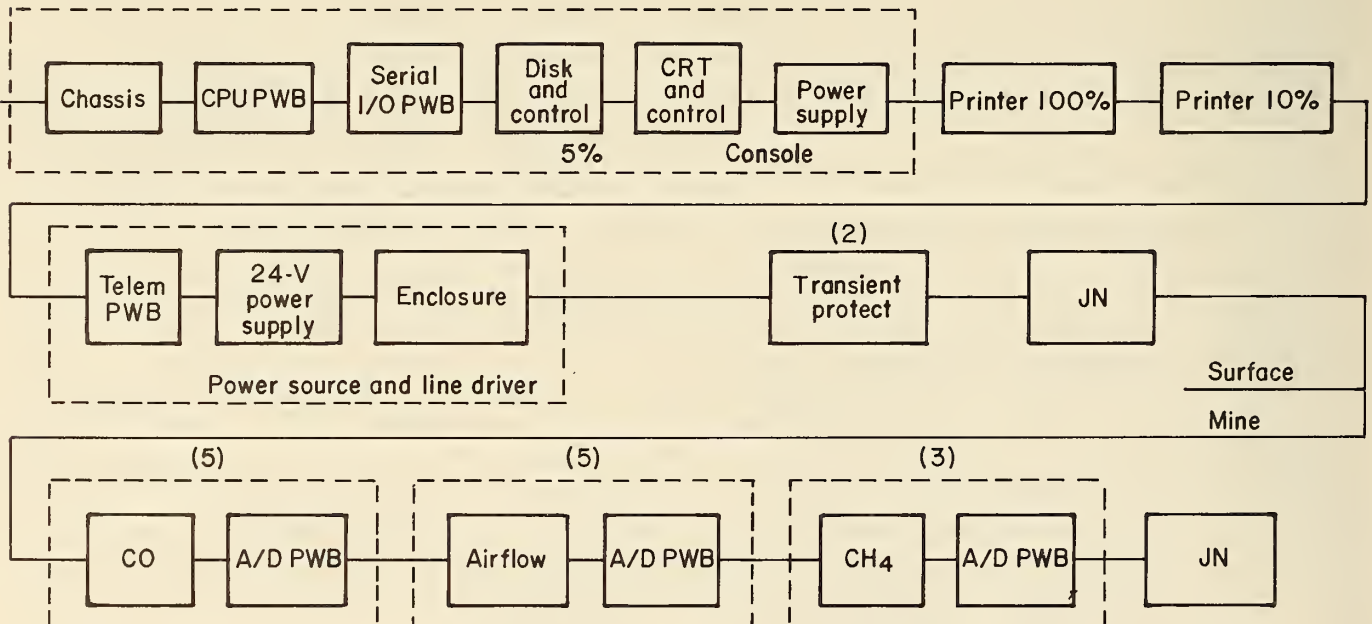


FIGURE 4.—System B reliability configuration.

PREDICTION DATA AND ANALYSIS

The data needed to perform the parts-count prediction were obtained from the schematics and parts lists of the various assemblies. A sample worksheet for the calculation is shown in figures 5 and 6. However, because of the proprietary nature of the monitoring systems, the actual number and type of components used for the calculations are not shown.

The failure rate $\left(\frac{1}{MTBF}\right)$ for a particular group of similar components is then derived by multiplying the number of components by the generic failure rate (obtained from 217D) and the appropriate quality factor. As an example, the

failure rate for 12 nonmilitary plastic resistors would be as follows:

$$\begin{aligned}\lambda &= (N_i)(\lambda_G)(\pi_Q), \\ &= (12)(0.0011)(3), \\ &= 0.0396.\end{aligned}$$

The failure rate for a particular assembly is then obtained by adding the failure rates for all of the components used. Likewise, the failure rate for a subsystem is obtained by adding the failure rates for each of the assemblies used. Finally, the predicted reliability of the system is derived using equation 2.

Family	Type	Qty.	λ_G	Quality factors			N λ I λ Q Level 1	N λ I λ Q Level 2	N λ I λ Q Level 3
				Jan	Nonmil hermetic	Nonmil plastic			
Semicondo.....	Transistor Si NPN		.016	1.0	5.0	10.0			
	Transistor SI PNP		.024	1.0	5.0	10.0			
	Diode SI gen purpose		.0031	1.0	5.0	10.0			
	Diode zener		.012	1.0	5.0	10.0			
	LED		.033	1.0	5.0	10.0			
RES.....	Power transistor		1.9	1.0	5.0	10.0			
	Composition RC		.0011	1.0	3.0	3.0			
	Film RL		.016	1.0	3.0	3.0			
	Film RN		.018	1.0	3.0	3.0			
	Wirewound RW		.18	1.0	3.0	3.0			
CAP.....	Var WW RA		1.10	1.0	3.0	3.0			
	Var comm RV		.14	1.0	3.0	3.0			
	Ceramic CX		.018	1.0	3.0	3.0			
	Tantilum solid CSR		.014	1.0	3.0	3.0			
	Tantilum nonsolid CSR		.28	1.0	3.0	3.0			
TFRS.....	Al dry CE		.29	1.0	3.0	3.0			
	Low power pulse		.019	1.0	3.0	3.0			
	High power pulse/power		.14	1.0	3.0	3.0			
Relay.....	Audio trans		.038	1.0	3.0	3.0			
	General purpose		.33	1.0	6.0	6.0			
	High current		1.1	1.0	6.0	6.0			
Conn.....	Circular/rack panel		.017	1.0	3.0	3.0			
	Printed wire board		.024	1.0	3.0	3.0			
PCB.....	2-sided board		.0029	1.0	1.0	1.0			
Switch conn...	Toggle and push button		.0029	1.0	20.0	20.0			
	Rotary		.96	1.0	50.0	50.0			
	Wirewrap		.000053						
	Wave solder		.0006						
	Hand solder		.0055	1.0	1.0	1.0			
Misc.....	Crimp		.001						
Microcircuits.		From page 2		8-2	0	0-1/NH			
Drawing reference		Assembly totals							
		Assembly Name _____			Site _____				

FIGURE 5.—Sample form for assembly-rate summary.

Bits	Qty.	ROMS				RAMS			
		Hermetic		Nonhermetic		Hermetic		Nonhermetic	
		λ_{GH}	$N_{\lambda GH}$	λ_{GNH}	$N_{\lambda GNH}$	λ_{GH}	$N_{\lambda GH}$	λ_{GNH}	$N_{\lambda GNH}$
1.320.....		.02		.03		.03		.04	
321-576....		.02		.03		.04		.06	
577-1120...		.03		.05		.06		.11	
1121-2240..		.05		.06		.08		.16	
2241-5000..		.06		.10		.13		.28	
5501-11K...		.09		.18		.29		.76	
11001-17K..		.12		.23		.44		1.2	
17001-38K..		.20		.44		.88		2.5	
38001-74K..		.33		.84		1.3		3.9	
		////		////		////		////	
Digital						Linear			

Gates	Qty.	Hermetic		Nonhermetic	
		λ_{GH}	$N_{\lambda GH}$	λ_{GNH}	$N_{\lambda GNH}$
1.20.....		.016		.018	
21-50.....		.020		.023	
51-100.....		.026		.031	
101-500....		.044		.06	
501-1000...		.071		.081	
		.063		.100	
1001-2000..		.11		.19	
2001-3000..		.14		.30	
3001-5000..		.20		.50	
5001-7500..		.28		.83	
7501-10K...		.43		1.3	
10001-15K..		.61		2.2	
15001-20K..		.85		3.4	
		////		////	

Transistors	Qty.	Hermetic		Nonhermetic	
		λ_{GH}	$N_{\lambda GH}$	λ_{GNH}	$N_{\lambda GNH}$
1-32.....		.031		.049	
33-100.....		.084		.16	
101-300....		.29		.79	
		////		////	
Summary					

Total	Hermetic total	Nonhermetic total
Digital.....		
RAM.....		
ROM.....		
Linear.....		
Total IC's....		
8-2x6.5.....		//////////
0x17.5.....		//////////
0-1x35.....	//////////	

Assembly Name _____ Site _____

FIGURE 6.—Sample form for microcircuit failure-rate summary.

The results of the reliability predictions for the two configurations are shown in figures 7 and 8. The results

on the assembly and subsystem levels are shown in figures 9 through 15.

ENVIRONMENTAL IMPACT ON EQUIPMENT

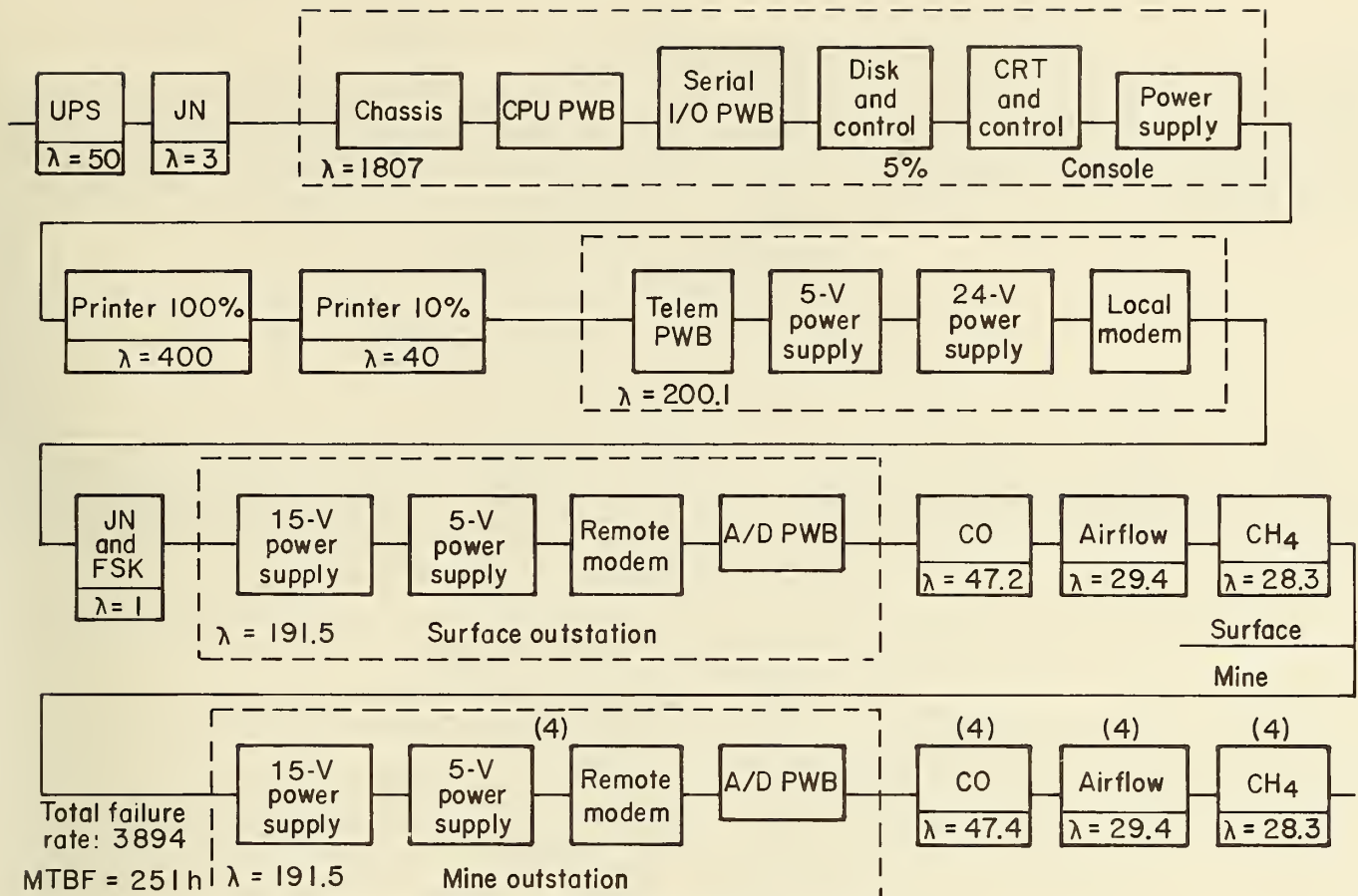
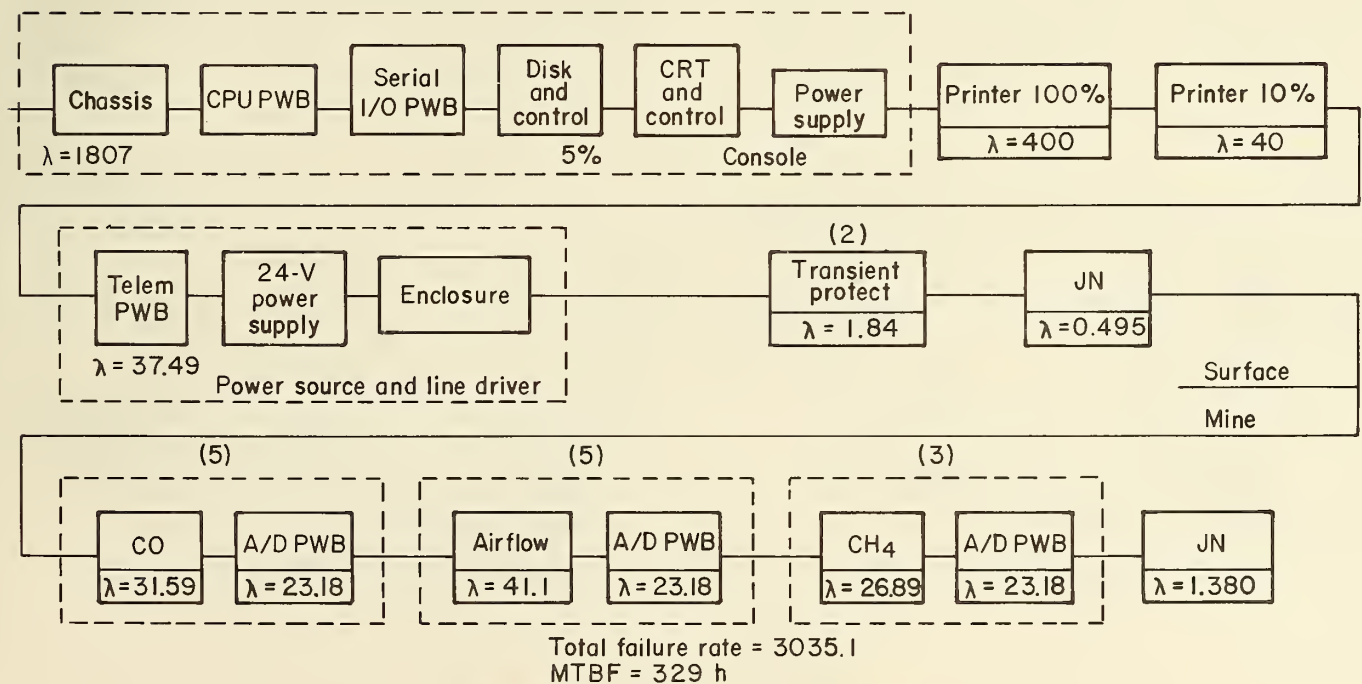
The previous predictions for the systems were performed using the MIL-HDBK-217D ground-fixed environment. However, as noted before, the handbook does not have a specific environmental factor that represents the operation of equipment in a mine atmosphere. It could be argued that this atmosphere is more severe than ground fixed because of the humidity and contamination-corrosion problems. On the other hand, it could be less severe owing to a lower ambient temperature. As

a result of this uncertainty, the environmental impact on the prediction results were reviewed. Table 2 shows how the MTBF varies as a function of environment and the conditions that define the environment in MIL-HDBK 217D. Figures 16 and 17 show the system reliability revised when a naval-sheltered environment is used for the equipment in the mine, and when a ground-fixed (G_F) environment is used for the surface equipment.

CONCLUSION

The predicted reliability of mine monitoring systems A and B using the

methodology presented in this paper are (on page 11) in hours:

FIGURE 7.— G_F environment for system A.FIGURE 8.— G_F environment for system B.

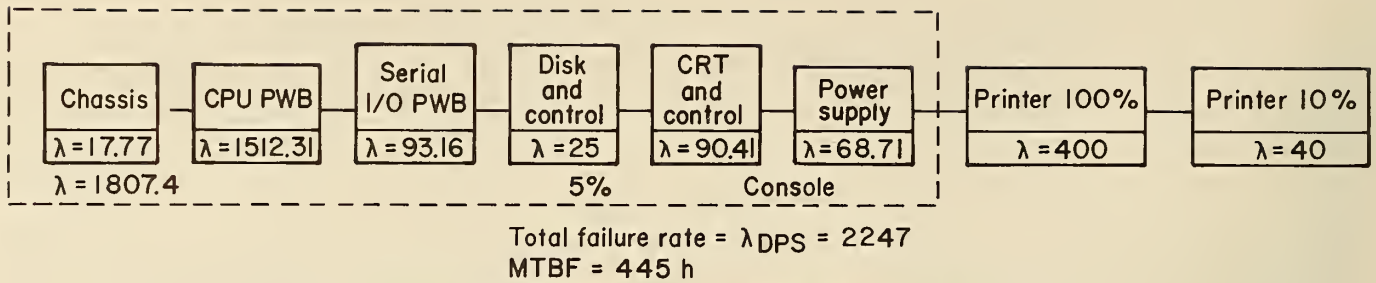


FIGURE 9.—Data processing subsystem for systems A and B.

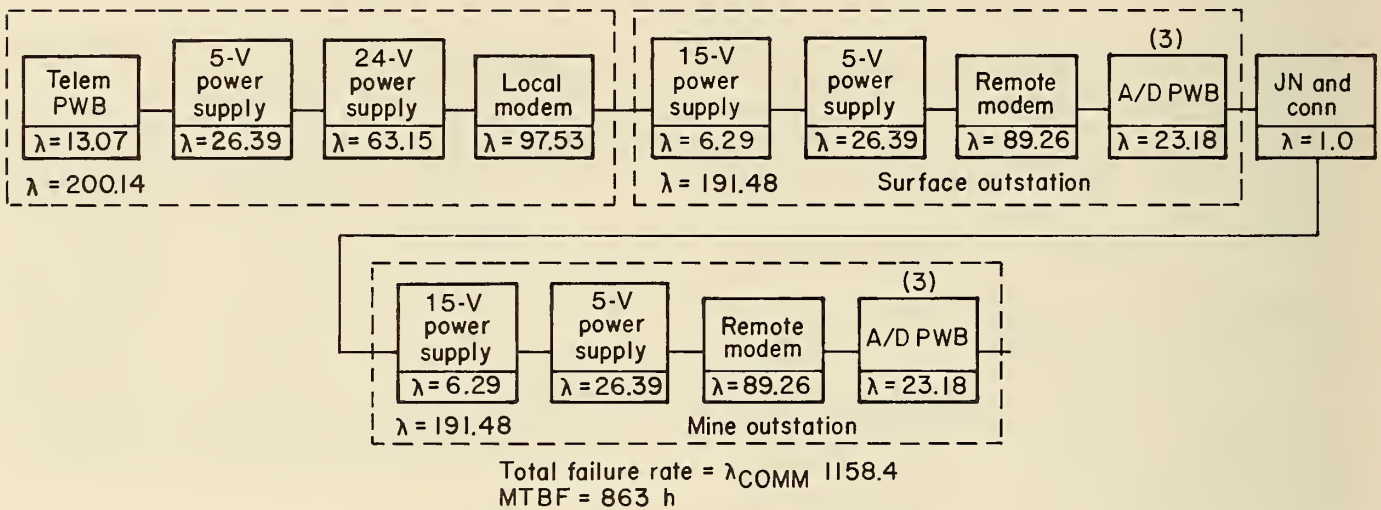


FIGURE 10.—Communications subsystem for system A.

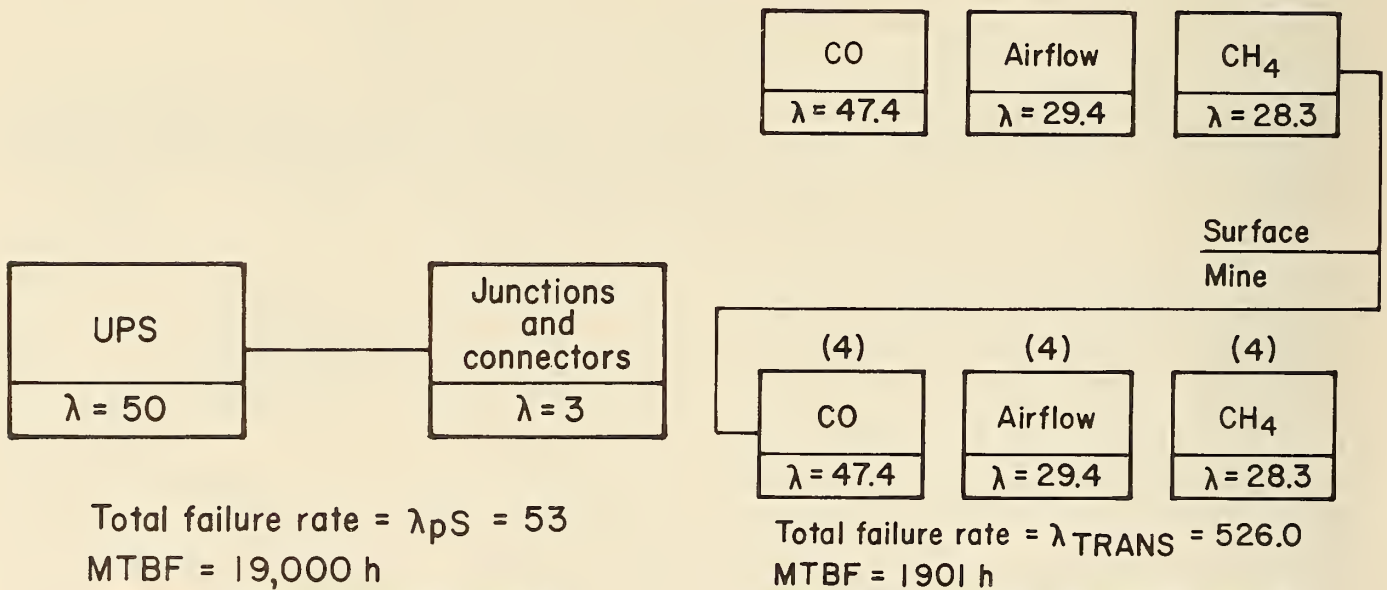


FIGURE 11.—Power subsystem for system A.

FIGURE 12.—Transducer subsystem for system A.

TABLE 2. - Environmental impact on equipment

MIL-HDBK 217 environment	Environment definition	T_A , °C	Example part E (IC)	MTBF adjust factor
Ground-benign (G_B).....	Nearly zero environmental stress with optimum engineering operation and maintenance.	30	0.38	0.21
Ground-fixed (G_F).....	Conditions less than ideal to include installation in permanent racks with adequate cooling air, maintenance by military personnel, and possible installation in unheated buildings.	40	2.50	1.00
Naval-sheltered (N_S).....	Surface ship conditions similar to G_F but subject to occasional high shock and vibration.	40	4.00	1.67
Naval-unsheltered (N_U)....	Nominal surface-ship-borne conditions but with repetitive high levels of shock and vibration.	75	5.70	3.15

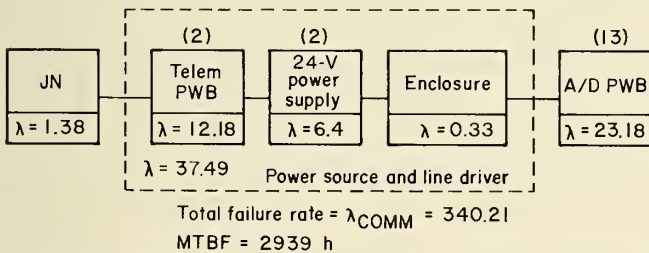


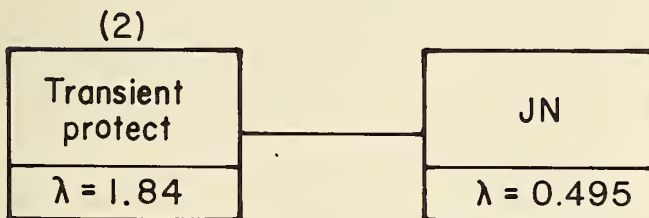
FIGURE 13.—Communications subsystems for system B.

Environment	System A	System B
Ground-fixed ¹	251	329
Naval-sheltered ²	209	283

¹For equipment on surface.²For equipment in mine.

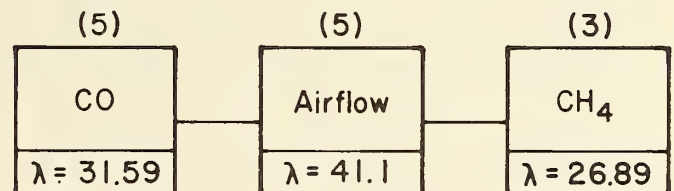
The actual reliability of monitoring systems in the field will be compared with the predicted reliability once a sufficient data base has been established.

Areas of potential improvements in reliability can be categorized as

Total failure rate = $\lambda_{PS} = 4.175$

MTBF = 239,521 h

FIGURE 14.—Power subsystem for system B.

Total failure rate = $\lambda_{TRANS} = 444.2$

MTBF = 2251.7 h

FIGURE 15.—Transducer subsystem for system B.

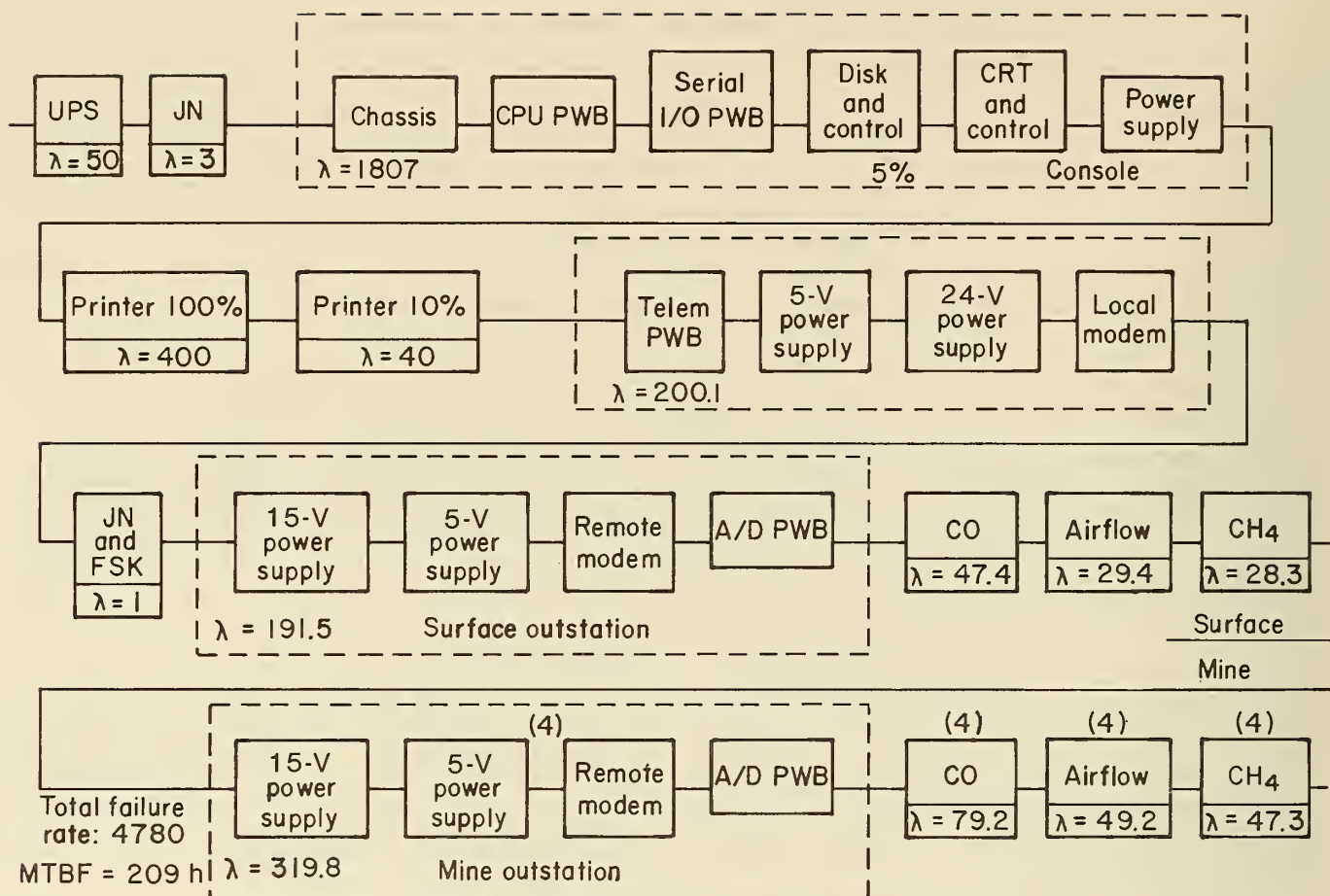


FIGURE 16.—System A reliability—adjusted.

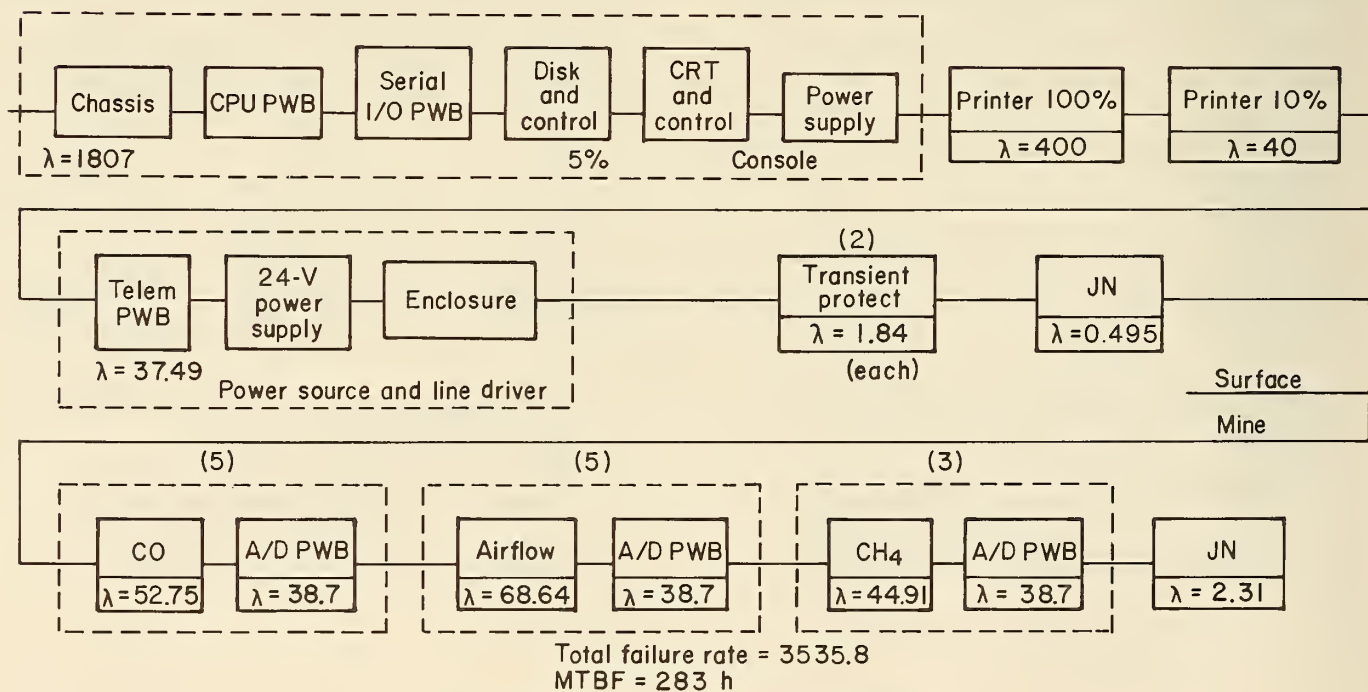


FIGURE 17.—System B reliability—adjusted.

part-quality upgrade and elimination of reliability design deficiencies. As previously defined in the prediction assumption, the baseline prediction was performed using standard-quality parts. Sensitivity to part-quality as a potential means of reliability is a proven fact based on field experience. Reliability of the system can be improved by doing the following:

- o Use hermetic devices in an atmosphere as corrosive and humid as that of a mine.

- o Use MIL-grade connectors and solder connections instead of integrated-circuit sockets.

- o Establish a well-defined inspection and preventive maintenance schedule.

- o All equipment should be burned-in at an elevated temperature for at least 100 h with the last 24 h failure free.

- o All printed circuit boards exposed to the mine environment be conformally coated to prevent moisture and corrosion problems.

- o System developments should involve front-end design consistent with the criticality of operation and safety in a severe environment.

BIBLIOGRAPHY

Donald, L. B., and R. M. Baker. An Annotated Bibliography of Coal Mine Fire Reports (contract J0275008, Allen Corp. of Am.). V. 1, BuMines OFR 7(1)-80, 1979, 98 pp., NTIS PB 80-140205; v. 2, BuMines OFR 7(2)-80, 1979, 400 pp., NTIS PB 80-140213; v. 3, BuMines OFR 7(3)-80, 1979, 654 pp., NTIS PB 80-140221.

Henley, E. J., and H. Kumamoto. Probabilistic Parameters of Whole Processes. Sec. 4.2.5 in Reliability Engineering and Risk Assessment. Prentice-Hall, 1981, p. 180.

Kacmar, R. M. Reliability of Computerized Mine-Monitoring Systems. BuMines IC 8882, 1982, 10 pp.

U.S. Air Force, Reliability Analysis Center. Rome Air Development Center Reliability Design Handbook. RDH375, Mar. 1976, pp. 19-21, 292.

U.S. Army Aviation Systems Command. Introduction to Reliability. Ch. 1.0 in Pocket Handbook on Reliability. Sept. 1975, p. 11.

U.S. Code of Federal Regulations. Title 30--Mineral Resources; Chapter I--Mine Safety and Health Administration, Department of Labor; Subchapter O--Coal Mine Safety and Health; Part 75--Mandatory Safety Standards--Underground Coal Mines; July 1, 1983.

U.S. Code of Federal Regulations. Title 30--Mineral Resources; Chapter I--Mine Safety and Health Administration, Department of Labor; Subchapter D--Electrical Equipment, Lamps, Methane, Detectors; Tests for Permissibility; Fees; Part 18--Electric Motor-Driven Mine Equipment and Accessories; July 1, 1983.

U.S. Mine Safety and Health Administration (Dep. Labor). Injury Experience in Coal Mining. Annu. Inf. Reps. 1973-80.

Watson, R. A. An Intrinsically Safe Environmental Monitoring System for Coal Mines. Proc., 6th Conf. on Coal Mine Electrotechnol., WV Univ., Morgantown, WV, July 1982, pp. 345-360.

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